Application of Remote Sensing and GIS in Water Quality Assessment

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1. General

Water is valuable natural resources that essential to human survive and the ecosystems health. Water provides variety purpose such as a source of water supply for domestic and industrial use, irrigated agriculture, livestock and mining activities. However by the increasing of the industrial development and anthropogenic activities the quality of water has decreased dramatically. The domestic's sewage, factories effluents, and agriculture waste can lead to deterioration of river water quality. The characteristic of water can be categorized into three namely physical, biological and chemical. In situ measurements and collection of water samples for subsequent laboratory analyses are currently used to evaluate water quality. These measurements are accurate for a point in time and space but do not give either the spatial or temporal view of water quality in wide space.

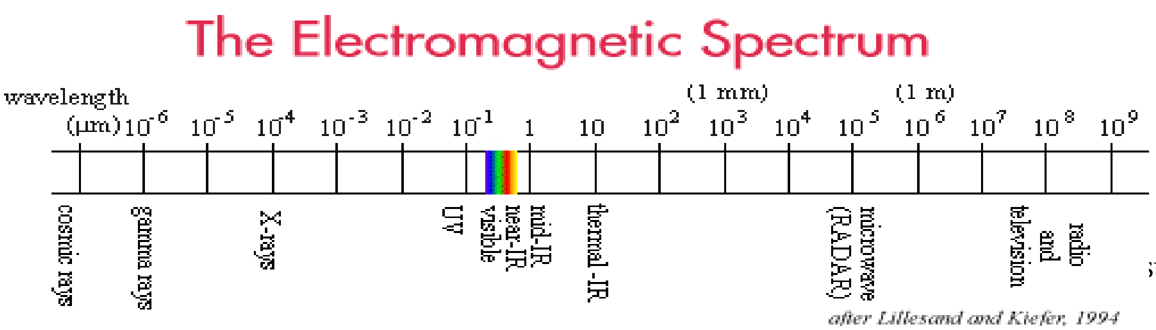
Therefore, the monitoring programs using Remote Sensing (RS) and GIS are needed to threats all contamination occurs and provides the effective action at all levels. The remote sensing and GIS techniques are the effectiveness, cheaper and valuable tools in monitoring water quality parameter in coastal level and fresh water bodies (lakes, river, ground water, and reservoir) compared to *in situ* where measurement is restricted to selected sampling points. The synoptic view provided by satellite remote sensing and the analysis capability provided by GIS offer a technologically appropriate method for studying various features related to water resources. Satellite remote sensing is an obvious source of data for mapping and map revision because of their repetitive nature to cover a wide area at relatively low cost. Before covering applications of RS and GIS in water quality studies, these two techniques in brief have been covered in the following sections.

2. Remote Sensing Techniques

Remote sensing is generally defined as observing an object from a distance without having direct contact with it. Remote sensing systems are used to observe the earth's surface from different levels of platforms such as satellites and aircraft, and make it possible to collect and analyse information about resources and environment over large areas. Satellite imagery offer a number of advantages over conventional survey techniques:

- ➢ Areal synoptic coverage (gives areal information as against point information through conventional techniques)
- ➢ Repetitive global coverage (for monitoring change)
- ➢ Real time processing
- ➢ Sensing of surrogates rather than the desired specific observation
- ➢ Multispectral coverage
- ➢ More automation i.e. less human error

The basic principle involved in remote sensing is that each object, depending upon its physical characters, reflects, emits and absorbs varying intensities of radiation at different EM wavelength ranges. Using information from one or more wavelength ranges, it is possible to discriminate between different types of ground objects (e.g. water, dry soil, wet soil, vegetation, rocks etc.) and map their distribution on the ground. One of the important remote sensing technique use is aerial photography. Aerial photography has essentially remained to the visible part of the electromagnetic spectrum where it is only a very small fraction of the electromagnetic spectrum. Remote sensing techniques have extended the scope of utilisation of the electromagnetic spectrum to almost its entire range.



The electromagnetic radiation (EM) is the source of all signals collected by remote sensing instruments. The source of this energy varies depending on the sensor characteristics. Most systems rely on the sun to generate all the EM energy needed to image terrestrial surfaces. These systems are called ***passive sensors***. Other sensors generate their own energy, called ***active sensors***, transmits that energy in a certain direction and records the portion reflected back by features within the signal path.

Electromagnetic energy can be generated by changes in the energy levels of electrons, acceleration of electrical charges, decay of radioactive substances, and the thermal motion of atoms and molecules. Nuclear reactions within the sun produce a full spectrum of EM radiation which is transmitted through space without major changes in its character until it reaches the atmosphere.

2.1 Image Interpretation

The main objective of image interpretation is to extract information about features displayed in an image. It is defined as the act of examining images for the purpose of identifying objects and finding their significance. The extraction of information depends on image analyst's experience, power of observation, imagination and patience. It also depends on his understanding of the basic principles of an image.

Any pictorial image can also be represented in digital form, so that the patterns of image brightness forms an array of numeric values which can be conveniently added, subtracted, multiplied, divided, and in general subjected to statistical manipulations that are difficult or impossible, if the image is available in pictorial form. Digital analysis encompasses a broad set of operations by which remotely sensed data are subjected to operations that yield information or enhanced data. It must be remembered that digital analyst is not totally free from human interactions. It requires significant inputs from the analyst while making decisions, thus providing information at faster rate, with high quality output, when compared with manual interpretations.

Image processing systems require various input/output devices, central processing unit (CPU), data storage devices and system consoles for man-machine interaction. Adequate image display facilities are important in the processing of an image.

The image processing software required in remote sensing applications can be broadly, grouped such as Data input routines, Pre-processing routines, Image display routines, Image enhancement and filtering routines, Classification routines, Image output routines.

An idealized sequence for digital analysis can be broken up into four specific groups;

a) Pre-processing
b) Enhancement,
c) Georefenceing and Mosaic
d) Analysis and Classification

3. GIS Techniques

GIS is a computer based technology for handling geographical data in digital form. It is designed to capture, store, manipulate and perform analyses of spatially distributed data. It contains both geometry data (coordinates and topographical information) and attribute data (i.e., information describing the properties of geometrical objects). In GIS we can make the presentation of results in both graphic and report form, with a particular emphasis upon preserving and utilizing inherent characteristics of spatial data.

3.1 Main Functions of GIS

♦ All GIS operations can, in principle, be done manually, but many tasks are so time consuming that they can be manually performed only for very small research areas. By using computers and their graphics facilities and a GIS software, the laborious tasks can be performed with ease. The early concepts of map handling by a computer had a serious drawback in that they could not handle the tabular or attribute data in conjunction with spatial features. This led to the development of additional methods and techniques where the spatial and attribute data both could be handled and integrated so that the outputs are more meaningful for planners and decision-makers. The upcoming of this technology has enhanced our capability not only of map handling but also of map manipulation and analysis. Therefore, using a GIS:

- Users can interrogate geographical features displayed on a computer map and retrieve associated attribute information for display or further analysis.
- Maps can be constructed by querying or analysing attribute data.
- New sets of information can be generated by performing spatial operations (such as polygon overlay) on the integrated database.
- Different items of attribute data can be associated with one another through a shared location code.

Before any spatial analysis or modelling operations can be carried out in a GIS, it is necessary to input the requisite data. Data input is the procedure of encoding data into computer-readable form and writing the data to the GIS database. The data to be entered in a GIS are of two types - spatial data and associated non-spatial attribute data. The spatial data represent the geographic location of features. Points, lines and areas are used to represent geographic features like a street, a lake or a forest land. These data will normally be obtained from one or more of the following sources:

- Existing maps
- Aerial photographs
- Satellite imageries
- Existing digital data
- Other GIS data bases

Remote sensing is an important source of data for GIS analysis and conversely, GIS data can serve as an important aid in image analysis. The need of integration of GIS and remote sensing is thus inevitable, and is rapidly emerging because of the complementry role played by these technologies.

3.2 Basic Types of Spatial Data

There are four elementary types of geometric entities designed to encode spatial data: Points, lines, polygons and continuous surface (area).

Point Data: Points are the simplest type of spatial data. Points can be of two kinds: observations relating to discretely distributed phenomena such as oil and water wells and observations relating to continuous distributions such as weather station reporting precipitation measurements of soil temperature.

Line data: Line entities are linear features made of many points or straight line segments made defined of two or more pairs of coordinates. The line entities can be static (structural type) or dynamic (flow). An arc, chain, or a string is a set of x-y coordinate pairs describing a continuous complex line.

Polygon or area data: Polygons constitute the most common data type used in GIS. They are bounded regions determined by a closed continuous sequence of many segments. The boundaries may be defined by natural phenomena such a land forms or by man made features such as forest stand or land use units.

Continuous surface: Examples of continuous surfaces are elevation (as part of topographic data), rainfall, temperature, etc. Most of the GIS systems handle these, essentially three dimensional data as topographic data, usually as Digital Elevation Model (DEM).

Traditionally spatial data has been stored and presented in the form of a map. Three basic types of spatial data models have evolved for storing geographic data digitally. These are referred to as : Vector and Raster

3.3 Capabilities of GIS

The power of GIS lies in its ability to analyse spatial and attribute data together. The large range of analysis procedures can be divided into four categories:

i) Retrieval, reclassification and measurement,
ii) Overlay,
iii) Distance and connectivity,
iv) Neighbourhood
v) Interpolation

3.3.1 Retrieval, Reclassification and Measurement Operation

In these functions retrieval of both spatial and attribute data are made and only attributee data are modified. New spatial elements are not created.

3.3.2 Retrieval Operations

These involve the selective search and manipulation and output of data. Retrieval operation includes the retrieval of data using:

- Geometric Classifications
- Symbolic Specifications
- A name of code of an attribute
- Conditional and logical statement

- Retrieval operations on the spatial and attribute data involve the selective search and manipulation, and output of data with out the need to modify the geographic location of features or to create new special entities. Retrieval operations include:

- Retrieval of data using geometric classification. Specifying the spatial domain of a point, line or area, retrieve all spatial entities and nonspatial attributes contained in the entire or in position of that spatial domain.
- Retrieval of data using symbolic specifications.
- Retrieve data using a name of code of an attribute. Retrieve using a name or code of an attribute. Example, retrieve effective depth and dominant texture of a given soil.
- Retrieval of data using conditional and logical statements. Retrieve data that satisfy alphanumeric conditions using logical expressions.

3.3.3 Reclassification Procedures

This procedure involves the operations that reassign thematic values to the categories of an existing map as a function of the initial value, the position, size or shape of the spatial configuration associated with each category, for instance a soil map reclassified into a permeability map. In a raster based GIS, numerical values are often used to indicate classes. A cell might be assigned value to indicate a class. For example a cell might be assigned the value 1 to indicate an agriculture land, 2 for forest land, and so on. Classification is done using single data layer as well as with multiple data layers as part of an overlay operation.

3.3.4 Measurement Functions

Every GIS provides some measurement functions. The measurement of spatial data involves the calculation of distances, lengths of lines, area and perimeter of polygons. The measurements involving points include distances from a point to a other point, lines or a polygon enumeration of total number as well as the enumeration of points falling within polygon.

3.3.5 Overlay Operations

Overlaying of maps results in the creation of a map where the values assigned to every location on that map are computed as a function of independent values associated with that location on two or more existing maps. Overlaying operation creates a new data set containing new polygons formed from the intersection of the boundary of the two or more sets of separate polygon layers. Arithmetical and logical overlay operations are common in all GIS software packages.

Arithmetical overlay includes operations such as addition, substraction, division and multiplication of each value in a data layer by the value in the corresponding location in the second data layer. Logical overlay involves the selection of an area where a set of conditions are satisfied.

3.3.6 Neighbourhood Operations

Neighbourhood operations involve the creation of new data based on the consideration of 'roving window' of neighbourhood points about selected target locations.

They evaluate characteristics of an area surrounding a specified target location. In all neighbourhood operations it is necessary to indicate one or more target locations, the neighbourhood considered around each target and the type of function to be executed on the attributes within the neighbourhood. The typical neighbourhood operations in most GIS are search function, topographic function and interpolation.

3.4 Interpolation

Nearest neighbor: This technique gives horizontal surfaces around each point. This technique is generally used for interpolation of the rainfall data. This provides weight to be used for the rain gauge stations, for finding average rainfall over a watershed.

Weighted average: A weighted average is taken of point elevation falling within a specified radius from the interpolation point. Weight is an inverse function of a distance between the point of unknown value (interpolation point) and that of known value (data points).

Weighted surface: Weighted surface fits a surface of n-degree using the elevations at points within a specified radius from the point of interpolation.

Trend surface: Trend surface fits an overall surface with the input data. It provides the global direction in which the variable changes.

Kriging / geostatistical method: Kriging is a mathematical technique developed by D.G. Krige for application in mining industry in South Africa. The experimental semi variogram is calculated from the data. A standard semi variogram equation is fitted to the experimental data using regression technique. This fitted curve is used in the interpolation. For groundwater data the spherical theoretical semi variogram model is best suited.

4.0 Applications of RS and GIS in Water Quality Studies

Water quality is the process to determine the chemical, physical and biological characteristics of water bodies and identifying the source of any possible pollution or contamination which might cause degradation of the water quality. These water quality indicators can be categorized as: (i) Biological: bacteria, algae, (ii) Physical: temperature, turbidity and clarity, color, salinity, suspended solids, dissolved solids, (iii) Chemical: pH, dissolved oxygen, biological oxygen demand, nutrients (including nitrogen and phosphorus), organic and inorganic compounds (including toxicants) and (iv) Aesthetic: odors, taints, color, and floating matter.

Basis for Using Remote Sensing Substances in surface water can significantly change the backscattering characteristics of surface water (Jerlov, 1976; Kirk, 1983). Remote sensing techniques depend on the ability to measure these changes in the spectral signature backscattered from water and relate these measured changes by empirical or analytical models to a water quality parameter. The optimal wavelength used to measure a water quality parameter is dependent on the substance being measured, its concentration, and the sensor characteristics. Major factors affecting water quality in water bodies across the landscape are suspended sediments (turbidity), algae (i.e., chlorophylls, carotenoids), chemicals (i.e., nutrients, pesticides, metals), dissolved organic matter (DOM), thermal releases, aquatic vascular plants, pathogens, and oils. Suspended sediments, algae, DOM, oils, aquatic vascular plants, and thermal releases change the energy spectra of reflected solar and/or emitting thermal radiation from surface waters which can be measured using remote sensing techniques. Remote sensing tools provide spatial and temporal views of surface water quality parameters that are not readily available from *in situ* measurements, thus making it possible to monitor the landscape effectively and efficiently, identifying and quantifying water quality parameters and problems.

Suspended sediments are the most common pollutant both in weight and volume in surface waters of freshwater systems. Suspended sediments increase the radiance emergent from surface waters in the visible and near infrared proportion of the electromagnetic spectrum (Ritchie *et al.*, 1976). *In situ*, controlled laboratory, aircraft and satellite measurements have shown that surface water radiance is affected by sediment type, texture, and colour, sensor view, and sun angles, and water depth. Remote sensing of monitoring water quality has been started in the early 1970's. Ritchie *et al*., (1974) were developed an early empirical approach to estimates suspended sediments general equation as follows: Y=A+BX or Y=ABX where, Y is the remote sensing measurement (i.e., radiance, reflectance, energy) and X is the water quality parameter of interest (i.e., suspended sediment, turbidity). A and B are empirically derived factors that this value are gained from statistical relationship which determined from spectral reflectance value and between the *in* situ water quality parameter. From the spectral reflectance it can give the information about the band or wavelengths suitable for that water quality parameter. This equation later on was applied by other researcher to estimates water quality parameter.

Monitoring the concentrations of chlorophyll (algal/phytoplankton) is necessary for managing eutrophication in lakes. Remote sensing has been used to measure chlorophyll concentrations spatially and temporally. As with suspended sediment measurements, most remote sensing studies of chlorophyll in water are based on empirical relationships between radiance/reflectance in narrow bands or band ratios and chlorophyll. Thus field data are collected to calibrate the statistical relationship or to validate models developed.

Periodic evaluation of sediment deposition pattern and the assessment of available live storage capacity in a reservoir is an integral component of the optimum water resources management. The conventional techniques of sedimentation quantification in a reservoir, like the hydrographic surveys and inflow-outflow methods, are cumbersome, costly and time consuming. Further, prediction of sediment deposition profiles using empirical and numerical methods requires large amount of data and the results are still not accurate. Remote sensing, through its spatial, spectral and temporal attributes, can provide synoptic, repetitive and timely information regarding the revised water spread area in a reservoir. By using the digital analysis techniques and the geographic information system in conjunction, the temporal change in water spread area is analysed to evaluate the sediment deposition pattern in a reservoir.

Thermal pollution exists when biological activities are affected by changing the temperature of a water body by anthropogenic activity. Remotely sensed data have been used to map thermal discharge into streams, lakes, and coastal waters from electrical power plants. Thermal plumes in river and coastal waters can be accurately estimated by remote sensing techniques. Mapping of absolute temperatures by remote sensing provides spatial and temporal patterns of thermal releases that is useful for managing thermal releases. Quantitative estimates of surface water temperatures also provide input for interpreting outputs from mathematical models of thermal plumes. Aircraft-mounted thermal sensors are especially useful in studies of thermal plumes because of the ability to control the timing of data collection. Seasonal changes in the temperature of surface waters can be expected. Such seasonal changes of ocean surface temperatures have been routinely monitored using AVHRR and other satellite platforms, leading to new insights into the role which oceans play in regulating weather and climate Ritchie *et al.* (1990) estimated surface temperatures of lakes along the Mississippi River using thermal data from Landsat TM. Thermal remote sensing is a useful tool for monitoring freshwater systems to detect thermal changes that can affect biological productivity. These techniques allow the development of management plans to reduce the effect of man-made thermal releases. Satellite imagery has been used to delineate lake margins, a technique particularly useful in remote areas or in shallow- water systems having fluctuating margins.

Water turbidity is an expression of the optical properties of water, which cause the light to be scattered and absorbed rather than transmitted in straight lines. It is therefore commonly regarded as the opposite of clarity. As water turbidity is mainly caused by the presence of suspended matter, turbidity measurement has often been used to calculate fluvial suspended sediment concentrations. The higher resolution satellite like IKONOS has a potential solution to the limitation of spatial scale.

5. Concluding Remarks

Remote sensing observations for water quality monitoring provide both spatial and temporal information of surface water characteristics. Remote sensing data provides the synoptic view of the water body, obtain to measures the characteristics of an area rather than a point, can integrate several characteristics with one composites measurements and ability to improve models with continuous or frequent feedback from satellite measurements. With present advanced satellite sensors, a large number of water quality information about suspended sediment, turbidity, Secchi disk depth, wave height, color index and surface water temperature can be observed on a regular basis. Remotely sensed data have the potential to provide knowledge of broad scale changes, the link between offshore and near-shore waters, and the ability to obtain a long-term, near-daily view of the region of interest indicating seasonal and inter annual variability. Other than that, by advanced technology from remote sensing it is a cheaper and repetitive quantitative technique for measuring water quality that will allow adequate management. Remote sensing technologies have many actual and potential applications for assessing water resources and for monitoring water quality, limitations in spectral and spatial resolution of current sensors on satellites currently restrict the wide application of satellite data for monitoring water quality. New satellites and sensors (hyper spectral, high spatial resolution) already launched or planned to be launched over the next decade will provide the improved spectral and spatial resolutions needed to monitor water quality parameters in surface waters from space platforms. Research needs to focus on understanding the effects of water quality on optical and thermal properties of surface waters so that physically based models can be developed relating water quality parameters to optical/thermal measurements made by remote sensing techniques.
